HEALTH TESTING WITH AUTOMATED TECHNIQUES*

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One of our world problems has been an inability to transpose the advances of modern science and technology to health-care practices. Similarly we have not yet transposed efficient industrial techniques of manpower utilization to health care.

It has been estimated that the aged population, to cite one of our pressing areas of concern, will increase by 62.4 million in 1980.[1] The entrance of the present middle-aged group into the age of chronic illness will further compromise our already restricted ability to provide health services.

Despite a slight increase in the annual number of medical school graduates, fewer physicians are in private practice. The net result is that the number of practicing physicians per 100,000 people is declining.[2]

Attempts at expansion of the medical-manpower pool either by increasing the number of graduates from existing medical schools or by increasing the number of medical schools are necessarily long-term goals that can well be overoptimistic. At best the first graduates would appear 10 years after the planning stage of new construction. An additional three to five years would be necessary to replace the health personnel withdrawn from the health-manpower pool to staff new schools.

INCREASED PROFESSIONAL PRODUCTIVITY

But there are other routes to the increased productivity of physicians. These include: 1) systems analysis of the medical field in the computer era, 2) use of medical assistants and the redistribution of available talent,

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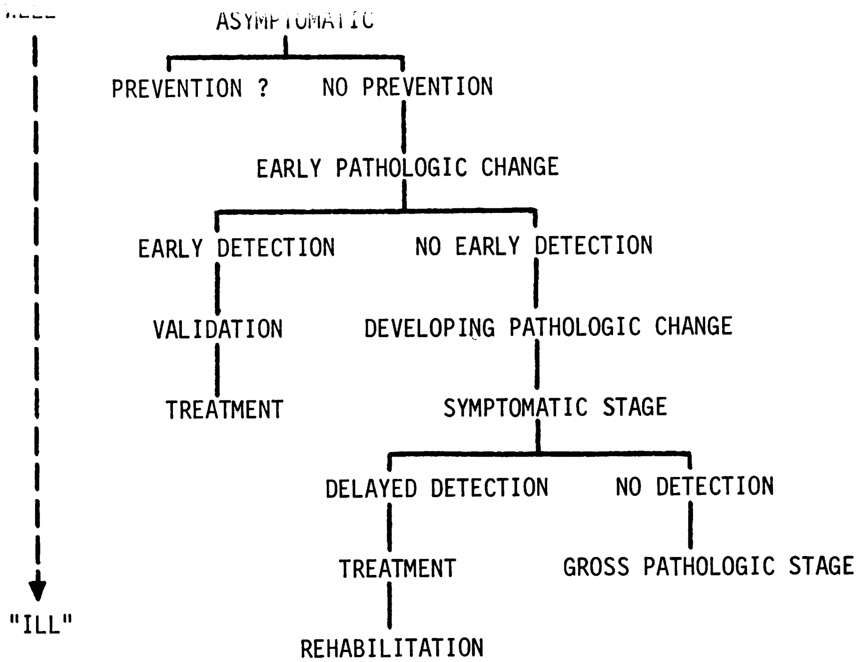

and 3) the application of automated techniques to assist the physician in the care of his patients. Automation, which seems most promising, can help us augment health services, define their quality, and maintain reasonable costs.

Health care implies a continuum for the identification of risk factors and primary prevention through the stages of treatment, rehabilitation, or demise (see accompanying diagram). Identification of risk factors and early detection of disease can help the physician arrive at an earlier diagnosis and develop a plan to challenge the progression of a patient's illness.

It is evident that most potential users of comprehensive medical care exist at the top extreme of such a continuum. The first requisite for a system that purports to lessen the number of persons traversing the full course of disease is to identify the factors at risk and to isolate those that are malleable.

Automated medical service and diagnostic systems that require semiskilled personnel for the acquisition of test data are the most promising means of providing the services required.

The task for physicians is clear: it is to stress preventive medicine so that more of their time can be spent in the care of the ill.

The task for engineers is also clear. It is to design medical systems that incorporate the machine, personnel, and management subsystems that can be implemented by existing manpower.

The task for health planners is clear as well: to study how we should use instrumentation for any repetitive task that would be drudgery or an uneconomical use of the time of highly trained and permanently scarce people such as physicians and registered nurses. Optimum use of machine systems as an aid to physicians and nurses can help us relieve the shortage of professionals now. But, most important, it can also enable them to serve at their highest level.

Instrumentation Systems

There are three possible types of systems that use instrumentation. The first is a fully automated medical system. Such a system without human beings at some point of operation does not now exist, nor is one in any stage of planning. Such a system may be inappropriate in the care of patients.

The second type, the "man-machine" system, does exist at present. The man-machine interface system of medical signal interpretation, for example, has been used for decades. The acquisition of the record requires a technician, and the interpretation requires a physician. This type of system can be considered inadequate for the demands now placed on our system for delivery of augmented health care.

Introduction of a digital computer into the man-machine interface system converts it into a semiautomated system. This type of system is now practical. It can help the technician correct and facilitate recording, and it could assist diagnosis at the first clinic visit. Programmed integration of results from such a system can also result in a modification of plans for the patient during the visit. The physician's diagnosis of disease will be of higher quality if it is done in the series that result from such a system, which can assist the physician in time-consuming interpretation of tests. Semiautomated sytems in series with statistical routines can be used to attempt predictive factors.

With a semiautomated system the experience of specialists can be brought immediately to every patient's bedside. Medical signals can be transmitted directly to the processing system by telephone or by mail.

The system can analyze the signals almost instantaneously, and the results can be mailed back to the sender or displayed on a teletype machine or other device in a few seconds.

As a result of trials and demonstrations, requests for services—either signal processing or consultation and use of the computer programs—have been received from several groups, which include Regional Medical Programs, state and local health departments, individual hospitals and clinics, industrial and labor groups, and population studies. We have analyzed the needs of these units and have concluded that their basic-processing needs can best be met by small specialized computers as part of a total data-collection, processing, and communications system. Today we routinely use a computer complex as a model of a dedicated system for the analysis of electrocardiograms and spirograms. We chose the electrocardiogram as the first signal for automated recognition and interpretation of patterns because physicians are familiar with it and because we have had 50 years of experience in relating its wave forms to specific clinical means. But we could have begun with almost any other physiological signal-electroencephalogram, including the spirogram, the phonocardiogram, and others. We have since demonstrated that each of these signals is subject to automated measurement and interpretation. Two examples of what is possible follow.

Spirometry

Despite its clinical value, the spirogram is little used in medical practice. In a recent survey conducted by the District of Columbia Thoracic Society, local practicing physicians were asked: "What per cent of your patients have chronic respiratory disease?" Eighty per cent of the physicians stated that fewer than 10% of their patients had chronic respiratory disease. Yet the experience of groups involved in mass testing for respiratory disease has shown that a minimum of 30% of subjects tested have chronic obstructive pulmonary disease.[3-5]

The clue may well be in testing. Only 56 of 323 (17%) of the physicians queried in Washington, D.C., had equipment for testing pulmonary function.

It is not surprising therefore that probably only one person in 1,000 has had a test of vital capacity and expired air flow, although broncho-pulmonary disease is among the most prevalent causes of disability. Our own experience in pulmonary testing would indicate that 30%

TABLE I. SPIROGRAPHIC MEASUREMENTS IN 1,510 ADOLESCENT MALES

Age / *Number*		*14* / *295*	*15* / *381*	*16* / *371*	*17* / *335*	*18* / *118*
F.V.C. (Ml.)	Mean	4,183	4,593	4,805	5,010	4,976
	S.D.	701	763	756	809	801
FEV_1 (Ml.)	Mean	3,317	3,615	3,882	4,071	4,046
	S.D.	718	731	704	655	827
Flow rate 200-1200 cc. (Ml./SEC.)	Mean	4,771	5,008	5,400	5,879	5,859
	S.D.	1,601	1,661	1,787	1,827	2,116
Flow rate 25-75% of FVC (Ml./SEC.)	Mean	3,835	3,834	4,123	4,332	4,371
	S.D.	1,125	1,124	1,067	1,188	1,264

TABLE II. CORRELATION COEFFICIENTS FOR SPIROGRAPHIC MEASUREMENTS AND HEIGHT-WEIGHT

	14	*15*	*16*	*17*	*18*	*All ages*
FVC	0.737	0.563	0.540	0.487	0.453	0.609
FEV_2	0.661	0.550	0.453	0.462	0.477	0.580
Flow rate 200-1,200 cc.	0.413	0.325	0.210	0.287	0.282	0.345
Flow rate 25-75% of FVC	0.466	0.396	0.289	0.219	0.379	0.403

TABLE III. FORCED VITAL CAPACITY*

Percentile	*Age 14*	*15*	*16*	*17*	*18*
2.5	2,839	3,054	3,456	3,500	3,089
5	3,079	3,313	3,644	3,811	3,754
25	3,760	4,033	4,279	4,494	4,511
50	4,208	4,467	4,808	4,965	4,944
75	4,610	4,895	5,304	5,440	5,477
95	5,187	5,810	6,021	6,505	6,068
97.5	5,574	6,105	6,252	6,655	6,420

*Volume in milliliters

TABLE IV. FORCED EXPIRATORY VOLUME AT ONE SECOND*

Percentile	*Age 14*	*15*	*16*	*17*	*18*
2.5	1,860	2,152	2,362	2,534	1,700
5	2,147	2,326	2,645	2,934	2,211
25	2,852	3,206	3,488	3,677	3,666
50	3,333	3,666	3,923	4,075	4,228
75	3,770	4,068	4,369	4,517	4,505
95	4,468	4,724	4,892	5,110	5,134
97.5	4,691	5,000	5,021	5,260	5,295

*Volume in milliliters

TABLE V. FLOW RATE AT 200-1200 ML.*

Percentile	*Age 14*	*15*	*16*	*17*	*18*
2.5	1,592	1,776	2,009	2,272	1,490
5	2,128	2,378	2,399	2,687	2,258
25	3,583	3,839	4,075	4,594	4,535
50	4,673	4,908	5,511	5,906	5,779
75	5,901	6,178	6,635	7,311	7,363
95	7,263	7,733	8,081	8,739	9,110
97.5	7,570	8,206	8.754	9,110	9,952

*Flow rate in milliliters per second

TABLE VI. FLOW RATE AT 25 TO 75% OF FVC*

Percentile	*Age 14*	*15*	*16*	*17*	*18*
2.5	1,567	1,567	1,943	1,509	1,347
5	1,862	1,862	2,353	2,179	2,118
25	3,182	3,182	3,464	3,623	3,586
50	3,855	3,855	4,156	4,368	4,398
75	4,665	4,665	4,800	5,020	5,185
95	5,572	5,572	5,762	6,116	6,252
97.5	5,744	5,744	6,211	6,611	6,538

*Flow rate in milliliters per second

of persons over 40 who walk into a multiphasic clinic will have an abnormal forced expiratory spirogram. Above 55 the prevalance of obstruction of airways exceeds 40% in ambulatory populations. Seventy per cent of heavy smokers over 55 can expect to have evidence of obstructive pulmonary disease on the spirogram.

A standardized method for measuring forced expiratory spirograms facilitates population studies. Ayers and his collaborators[11] used our present system in investigating approximately 1,500 adolescent boys from a school district in Columbus, Ohio. Spirograms were obtained. The spirographic results for each age are listed in Table I. The association of height and weight with specific spirographic measurements were poor (Table II). Percentile distribution of the measurements for each year are shown in Tables III through VI.

Similar applications of our computer programs are currently under way for epidemiologic studies, multiphasic clinics, and industrial-health programs.

Analysis of the spirogram by a physician may require 15 minutes for a minimum number of computations; extraction of this and of even additional information from the spirogram takes the computer about 30 seconds.

This computer service can aid the physician in interrelated cardiopulmonary diagnosis. It is important in any cardiovascular examination, yet is is almost completely ignored. But let us not misinterpret that statement. A cardiologist should not rush out and take a two-week course in pulmonary physiology. Rather he can and should get the results from a computer-processed spirogram from a multitest station. At present he has enough background to use the results.

Television Ophthalmoscopy

Television ophthalmoscopy is a relatively new technique for visualizing the ocular fundus with a reliable, objective instrument. It holds immense potential as a method of retinal investigation for teaching, basic research, clinical testing, and epidemiology. The instrumental system can produce electrical signals directly from the fundus image. These can make possible the extraction of new and more precise information from the retina by the monitoring of dynamic microvascular events, mass-screening studies with convenient storage of data, and automatic computer analysis of the data. Image processing is still in the future, but it can become the next development in computer methodology in medicine.

Advantage to the Physician

How can a physician benefit from semiautomated multitest results? In a typical clinic less than 2% of chest x rays will be abnormal. However other medical signals when analyzed rapidly can be used to predict a probability of which subjects are most likely to have an x-ray abnormality. Each of the data sources–questionnaire, spirogram, and electrocardiogram–can be analyzed by computer techniques. Simulated rapid correlation of these results could have been used to identify the subjects most likely to require an x ray and any other precise categorizing test without recall and rescheduling. Further, the analysis of an x ray with a hard data background of information can facilitate the x-ray analysis.

Prior investigations[6, 7] show that more than 30% of persons who attend hospital outpatient departments have electrocardiographic and respiratory abnormalities that require clinical attention. Screening units report 20 to 35% of abnormal spirograms and electrocardiograms; the percentages depend on the age groups studied. Hochberg has shown the results in a group of dentists.[8] The average age of the participants was 46 years. As expected, the incidence of abnormalities rose with age. Over all, 32% of the participants had questionable electrocardiograms, a figure comparable to that found in previous health-evaluation programs of the American Dental Association.

It would require several hours for a cardiologist to measure the electrocardiographic waves and calculate the parameters with the accuracy of the computer system. An electrocardiographic interpretation alone, performed in the detailed manner of the computer, would occupy several minutes of a cardiologist's time. In one demonstration essentially the time of only one physician was involved in the recording of analysis of more than 1,400 electrocardiograms in a three-day period. The magnitude of the time saved is apparent. The computer can help a cardiologist to interpret three to five tracings in the time previously required to interpret one, and the reproducibility of the computer can help him to improve his accuracy.

Through the use of the telephone transmission system, the computer can help the physician perform as an expert cardiologist. A physician will benefit both by receiving aid when he needs it and by using this tool as a teaching aid to challenge his own ability.

Dobrow, Fieldman, and their collaborators[9] have shown results from the Hartford Hospital in this regard. In a series of 194 electrocardiograms read by the computer and by electrocardiographers there were 40 major diagnoses missed by physicians. During the same study, the average time spent per cardiogram by a physician using the computer printout was 32 seconds. Three weeks later, the same physician read the same cardiograms but without the benefit of computer printouts. The average time spent per cardiogram was 2 minutes, 27 seconds. Thus there was approximately a fivefold reduction in the time spent by physicians on their reviews as compared to the time it took to obtain similar data from computers.

Rosner[7] has shown that an altered spirographic recording was observed in 30 of 77 outpatients at a medical clinic. Twenty-three of the 40 patients with symptoms of respiratory dysfunction produced abnormal spirograms. Since respiratorylike symptoms are often due to causes outside the pulmonary system, an abnormal spirogram should not be expected in all subjects who report fatigue or breathlessness. Contrarily, an abnormal spirogram may be the only evidence of early malfunctions of the ventilatory system.

In an attempt to determine the value of several measures extracted by the computer from the forced expiratory curve, a physician obtained a cardiopulmonary history and performed a chest examination. On the basis of the history and physical findings but without knowledge of the pulmonary function studies the patients were placed in one of these categories:

Positive. The patients in this group gave complaints of cardiorespiratory problems (cough, wheeze, dyspnea, orthopnea) of one or more years' duration with confirmatory evidence from the examination performed by physicians.

Negative. These subjects had no cardiorespiratory symptoms and had no evidence of cardiopulmonary disease on examination.

Intermediate. Respiratory complaints were given by these patients but no physical evidence of cardiopulmonary disease was demonstrable by physical examination.

The five spirographic measurements were the forced vital capacity (FVC) expressed as a percentage of the predicted, forced expiratory volumes at one (FEV%), two, and three seconds expressed as a percentage of the performed vital capacity and the maximum expiratory flow rate. Correlation coefficients were determined for each of the measurements in the "positive" and "negative" groups. When discriminant function analysis was performed, the forced vital capacity as a percentage of the predicted vital capacity and the two-second volumes as a percentage of the observed vital capacity (FEV 2%) were the two variables of those examined that contributed most significantly to the discriminant. The finding that the FEV 2% had the greatest discriminatory power of the several flow-volume measurements must be tempered against the fact that the time-volume measurements were highly correlated with one another. The significance of the individual weight assigned to each variable in the discriminant-function equation is not a test of the complete contribution of that variable. Since the majority of patients in the positive group had a measurable obstructive ventilatory defect, a positive correlation among the flow-sensitive measurements was expected. A positive correlation among these parameters was also observed in the negative group with the exception of the maximum expiratory flow rate.

The significance of this exception may be related to the apparent normalcy of this measurement in subjects with mild expiratory obstruction.

Seven patients with abnormal tests were classed in the negative group as clinically free of respiratory symptoms and physical findings. A major limiting factor in clinical spirometry is the cooperation of patients. Fatigue, failure to comprehend the instructions, or poor coordination may produce abnormal values. These factors may explain the discrepancy between clinical impression and the abnormal spirometric score in these cases. We have directed efforts toward the standardization of test performance and reproducibility.[10] At times, however, the diagnosis of respiratory disease may evade the taking of a history and a physical examination. Repeated evaluation and additional laboratory aids (e.g., chest x-ray films and other pulmonary function tests) should be used to substantiate the spirometric observations.

The findings in the indeterminate group cannot be interpreted in terms of sensitivity and specificity of the spirogram because the clinical data are not conclusive. Ultimately a portion of this group will be judged to have significant respiratory dysfunction. The true value of the analysis will be reached only after adequate follow-up study of this group is made to determine the predictive value of the score.

Comments

The developments in automation will make possible the emergence of regional medical data centers with which small hospitals, nursing homes, and individual practitioners will have direct access by telecommunication.

These centers will make integrated analyses of medical and laboratory tests of a wide variety and will provide a valuable supportive service to institutions and physicians.

This will also permit a rebirth of preventive medicine. Many groups have studied and developed the logistic flow of people through many components of the physical examination, medical history, and laboratory tests. Several have already demonstrated that evaluations of health, which people need on a regular basis, can be done efficiently and economically. The addition of automated analysis and interpretation can provide even higher quality care and can effect further significant cost reductions and economies in the time of physicians and laboratories.

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